



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(21) International Application Number: PCT/US90/04318 (22) International Filing Date: 1 August 1990 (01.08.90) (30) Priority data: 391,864 8 August 1989 (08.08.89) US (71) Applicant: THE PENNSYLVANIA RESEARCH CORPORATION [US/US]; 114 Kern Graduate Building, University Park, PA 16802 (US). (72) Inventors: GORDON, Bernard ; 157 Hartswick, State College, PA 16803 (US). SHARMA, Prabodh ; 200 Highland Avenue, 111 Regency Square, State College, PA 16801 (US).		(74) Agent: MONAHAN, Thomas, J.; The Pennsylvania State University, 306 West College Avenue, University Park, PA 16801 (US). (81) Designated States: AT (European patent), AU, BE (European patent), CH (European patent), DE (European patent)*, DK (European patent), ES (European patent), FR (European patent), GB (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent). Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>
(54) Title: HYDRODEGRADABLE POLYESTERS (57) Abstract Hydrolysable polyesters based upon the random copolymerization of aromatic and absorbable aliphatic polyesters are disclosed. The copolymers are of particular value in polymer articles and fibers that are routinely discarded after use.		

DESIGNATIONS OF "DE"

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HYDRODEGRADABLE POLYESTERS

Products made from polymeric materials have become a major environmental concern due to the difficulty in disposing of the spent products. The advantage of utilizing polymeric materials having infinite lifetimes to manufacture such items as disposable containers, fishing lines and nets, and disposable diapers has become an increasing environmental concern when these items are indiscriminately discarded into the environment. One solution proposed for reducing plastic wastes from these spent items is to design new polymers, or modify existing polymers, such that these newly developed plastics undergo degradation once the useful lifetime of the product is over and they are discarded.

Polymers may be made to degrade as they are continually used or after they are disposed by several different mechanisms. However, while each mechanism has its own advantages, each also has its faults.

Polymers may be made to degrade by photochemical means, for example. Thus, when the polymer is exposed to sunlight over protracted periods, it undergoes certain chemical changes resulting in its degradation. These polymers have a serious fault, however, in that the polymer will not degrade if the item is not exposed to the correct wavelength of sunlight. Thus, if the items made from a photodegradable polymer are discarded in a land fill, they will be buried, sunlight will not be able to reach the polymer, and degradation will not take place. Recycling of these materials is also difficult; there is no way of knowing how much degradation has occurred and the resulting new end groups on the polymer are ill defined.

Polymers may also be made to degrade by microbial means as well. Two such polymers are polycaprolactone (which is not a polymer of choice for many applications because of its poor overall physical characteristics) and blended polymers containing a enzymatic digestible component. One example of such a blended material is polyethylene which incorporates a enzymatically degradable starch within the polymer backbone. When this polymer is discarded, enzymes produced by various bacterial and fungal species will attack the starch portions of the polymer, digesting it and leaving a very porous polyethylene residue which, unfortunately, stays in the environment.

Although aliphatic polyesters are well known to degrade by hydrolysis, aromatic polyesters that are commonly used for fibers and molded articles have been shown to undergo little, if any, degradation. A number of degradable polymers have received patents in the United States. For example, Stager and Minor have obtained United States Patent 3,647,111 for a biodegradable soft drink can; Henry has obtained United States Patent 3,676,401 for a photodegradable polyethylene film; Brackman has obtained United States Patent 3,840,512 for degradable polyethylene; and Guillet and Dan have obtained United States Patent 3,878,169 for a photodegradable polyester.

In general, polyesters and copolyesters, as well as the preparation of these polymers, are described in both the scientific and patent literature. Carothers et al [*Journal of the American Chemical Society* 52:3292 (1930)], for example, describes the ester interchange reaction of various diols (such as ethylene glycol or 1,4-butanediol) and diesters to

yield polymer. The preparation of polyesters of fiber-forming quality from dicarboxylic acids and diols is described in United States Patent 2,952,652.

We have now discovered that copolyesters of aromatic and aliphatic types can be made to degrade over a period of time and with exposure to water, under hydrolytic conditions. Thus, commercially used aromatic polyesters can be made to degrade after expiration of their useful lifetime by randomly incorporating a hydrodegradable link polymer into the polymer backbone by conventional copolymerization or transesterification of the reactant monomers. Depending upon the aliphatic comonomer and the amount used in the manufacture of the final polymer, the time for the loss of the physical properties of the polymer can be adjusted and thus degradation controlled. An additional advantage of the polymers according to the present invention is that the hydrolytic degradation cleanly forms oligomers with acid and alcohol end groups. The Degraded material could then be recycled by the repolymerization of these new end groups.

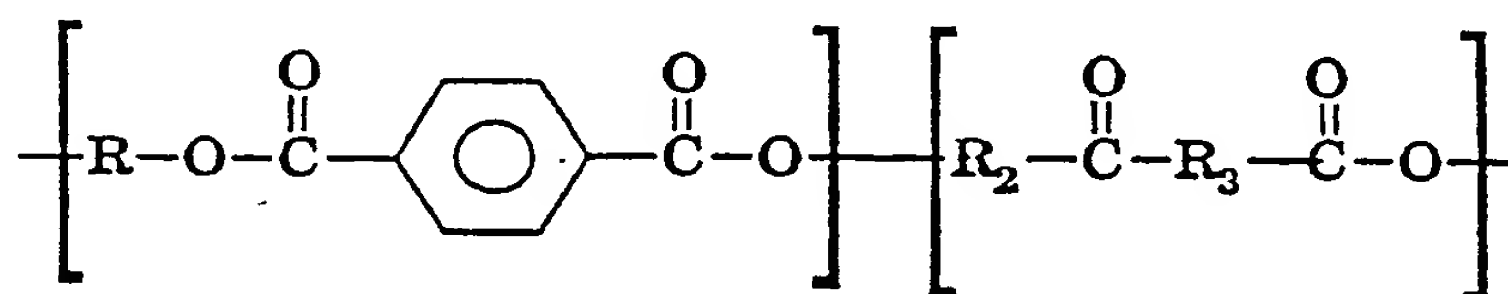
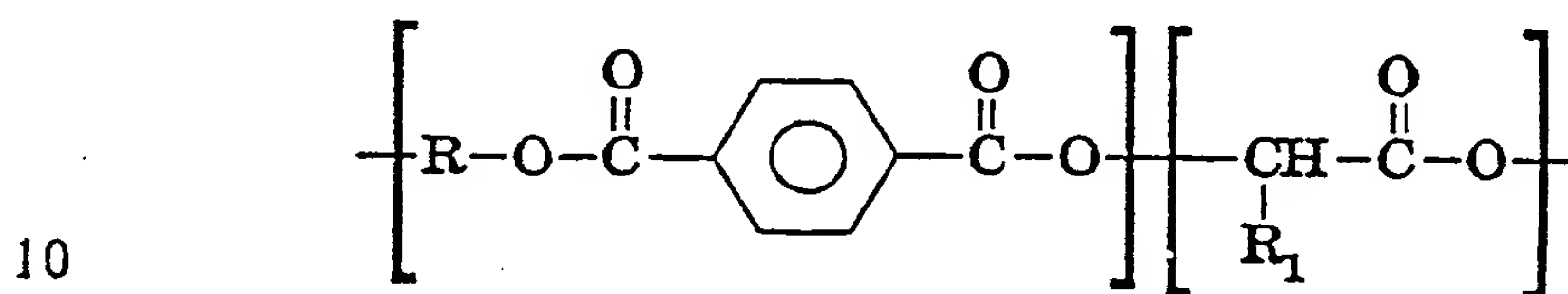
Prior to our invention, there was little appreciation or recognition in the prior art of the hydrolysis of a copolymer containing mostly aromatic polyester units. In particular, there has been no suggestion of manufacturing environmentally degradable aromatic polyesters by the inclusion of aliphatic links susceptible to hydrolysis.

The copolymer formulations according to this present invention are degradable polyesters made from aromatic and aliphatic polyester moieties. Depending upon the amount and type of aliphatic unit used in

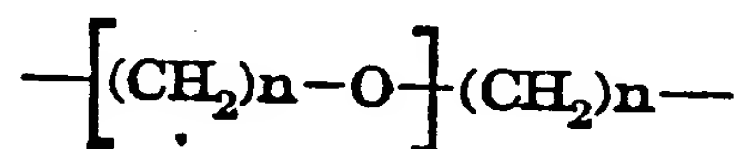
the formulation of these copolymers, the resultant copolymers will have limited (and varied) lifetimes upon exposure to water before they degrade. The environmentally degradable copolymers according to the present invention are of particular value for polymer articles and fibers

5 that are routinely discarded after use.

In general, the copolymers of the present invention are comprised of moieties having the general formula:



15 wherein R is a straight or branched alkylene moiety of 2 to 16 carbons, most preferably an alkylene moiety of 2 or 4 carbons, in length, or a polyether moiety of the formula:



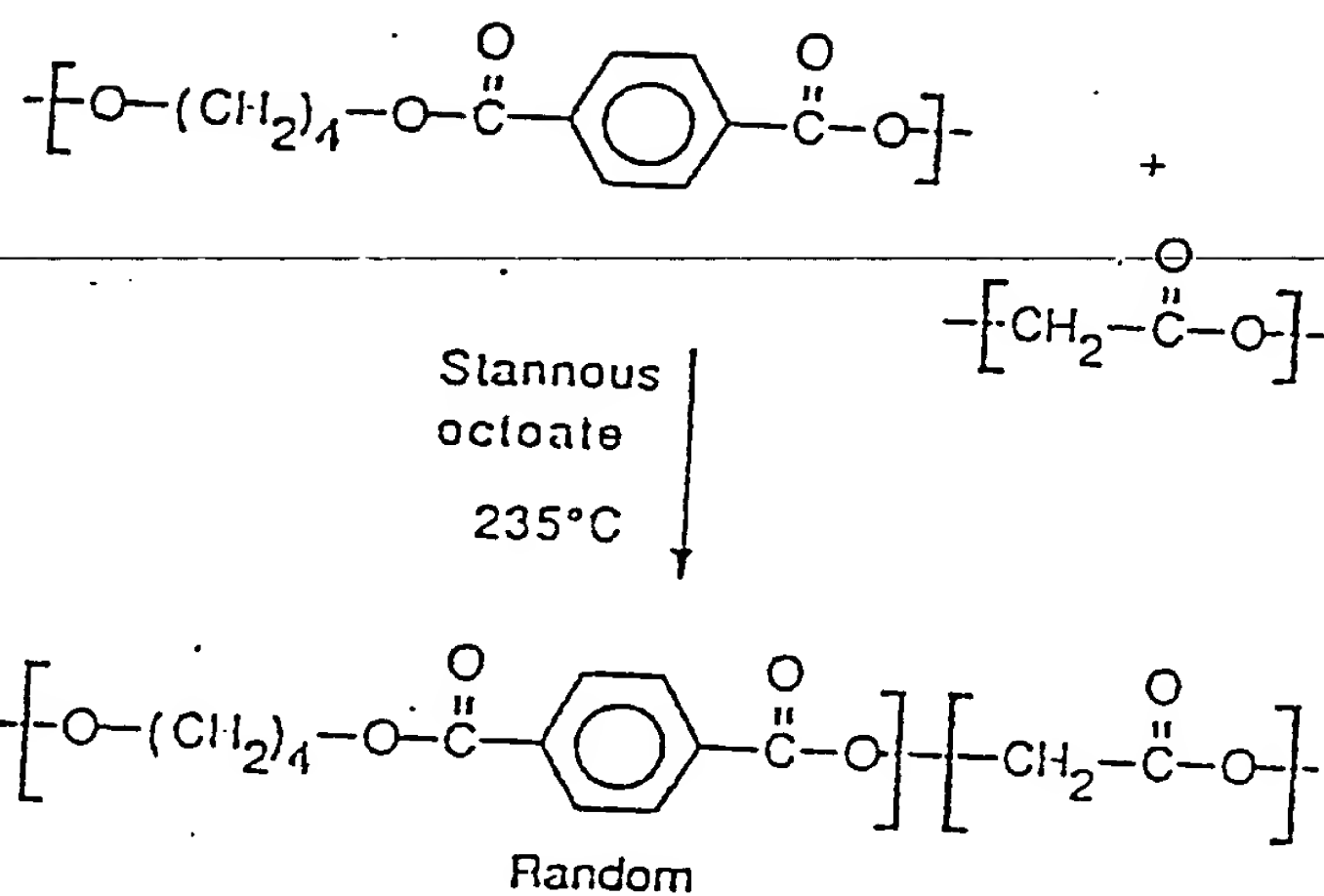
20 wherein n is a number from 2 to 16; R₁ is hydrogen or a lower straight or branched alkyl moiety of 1 to 10 carbons in length; and R₂ is a straight or branched alkylene moiety of 3 to 16 carbons, most preferably an alkylene moiety of 4 or 10 carbons, in length; and R₃ is a straight or branched alkyl moiety of 0 to 40 carbons, most preferably a straight moiety of 0 or
25 4 carbons or a branched moiety of 22 carbons.

More specifically, the random copolymers of the present invention are comprised of a polyester polymer such as, for example, polyethylene terephthalate; polybutylene terephthalate; polyarylates such as poly bisphenol-A terephthalate; aliphatic polyester blocks in polyurethane block copolymers; polycarbonates; the polyester portion of polyether polyester segmented block copolymer thermoplastic elastomers; and ester or alcohol terminated telechelic polymers. The polyester polymer is randomly interrupted with a hydrodegradable link polymer such as polyhydroxy acids such as polyglycolic acid, polylactic acid, polycaprolactone, polyhydroxy butyrate, and polyhydroxy valerate; polyaliphatic esters such as polybutylene oxalate and polyethylene adipate; polyalkyl anhydrides; polyalkyl carbonates such as polyethylene carbonate and polybutylene carbonates; and polyesters containing silyl ethers, acetals, or ketals.

The random copolymers of the present invention are conveniently prepared by either ester interchange reaction between the appropriate alkylene diol, diester and ester alcohol or appropriate dimer; or by transesterification reactions of the two homopolymers with the appropriate transesterification catalysts above the melting point of the two polymers.

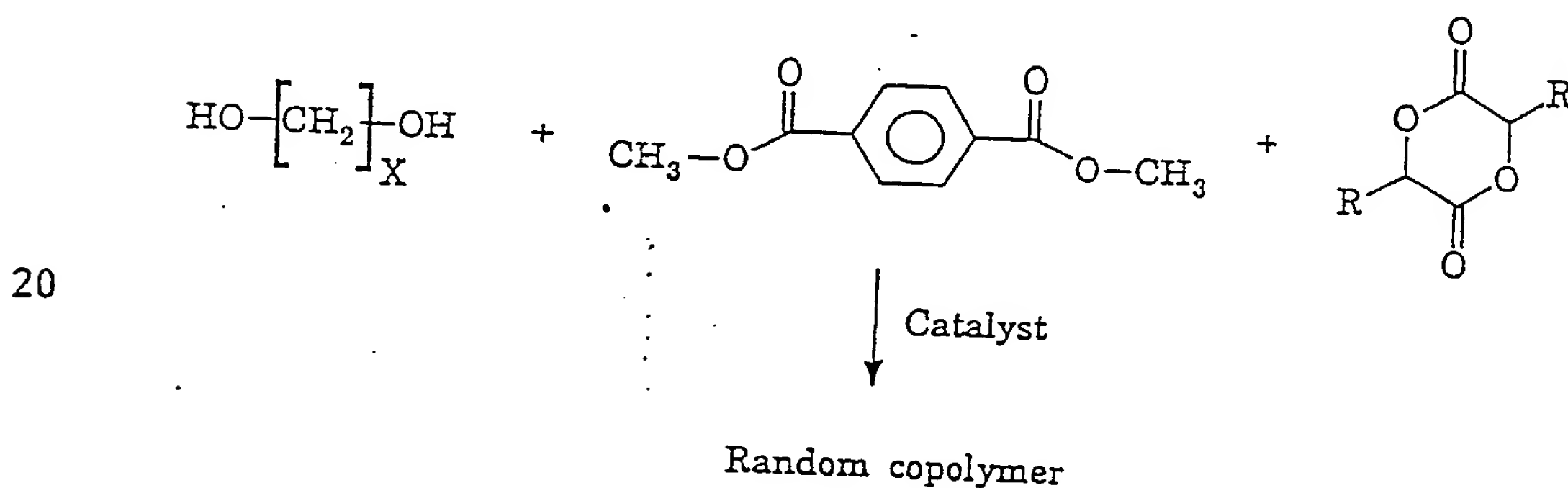
In general, a copolymer according to the present invention may be prepared by the transesterification of two homopolymers. An example of such a transesterification is the modification of a known polyester, polybutylene terephthalate (PBT), with polyglycolic acid (PGA) according to the following reaction:

5



Other methods may be used to prepare copolymers according to the present invention. For example, copolymers may be prepared from the monomer according to the following reaction sequence:

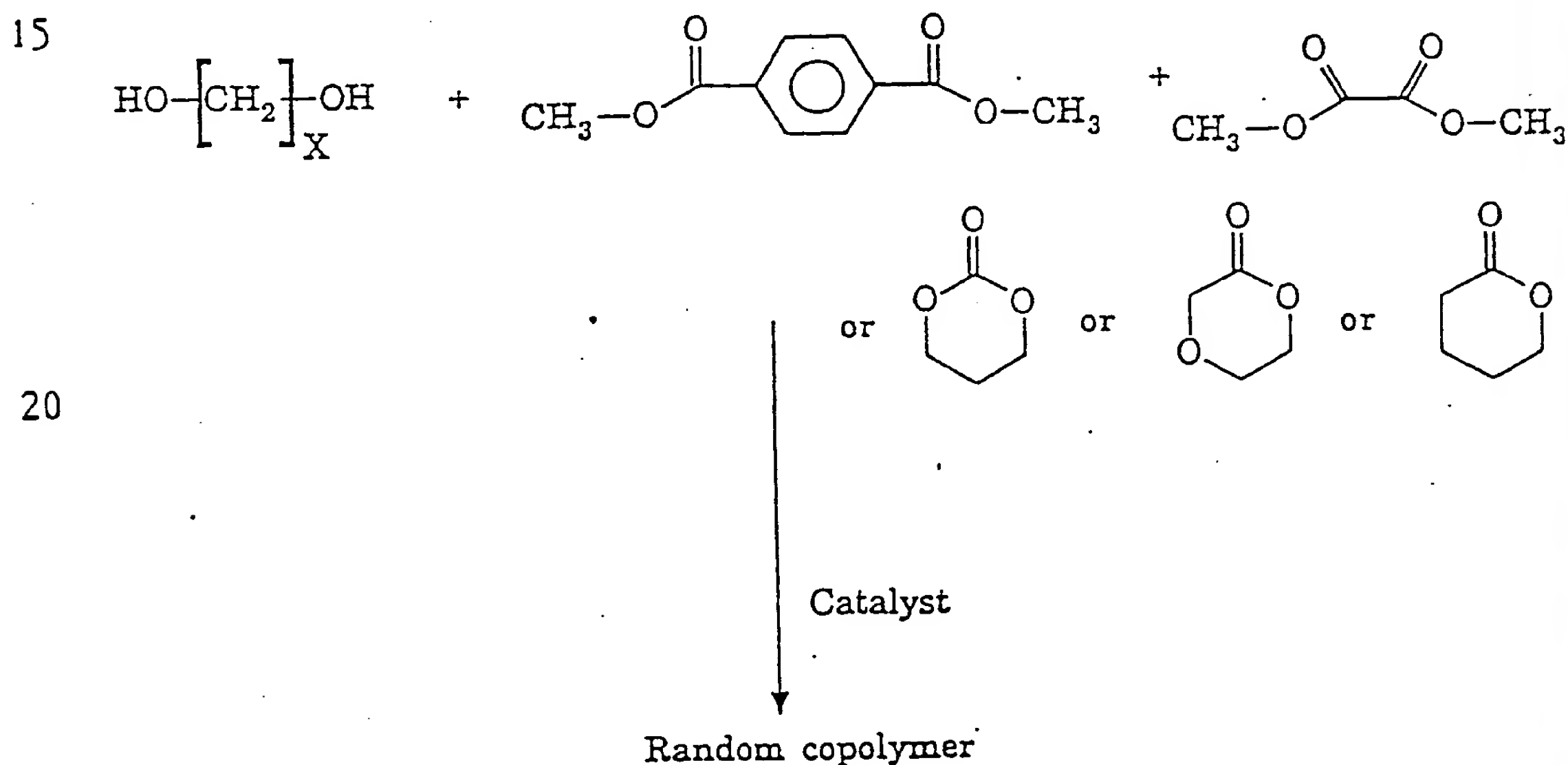
15



20
25 wherein R is hydrogen and X is 4.

In addition, a number of monomers may be substituted in this reaction. For example, polyethylene terephthalate or PET could be used in this reaction sequence by changing the polymer in transesterification or by changing the value of X to 2.

- 5 The hydrodegradable link polymer in the copolymers according to the present invention may be other than a glycolide moiety, as shown above. For example, the hydrolyzable moiety which becomes the hydrodegradable link polymer in the copolymer may be a lactide (R=CH₃) or larger alkyl moiety. Other possible alternatives for use as the
- 10 hydrodegradable link polymer in the copolymer according to the present invention are oxalate (PO), adipate, p-dioxanone, 1,3-dioxan-2-one, caprolactone, siloxane, or anhydride moieties. These additional hydrolyzable links can be used as homopolymers for transesterification (or as monomers) according to the following reaction sequence:



A more thorough understanding of the process for making the random copolymers of the present invention may be obtained from the following examples which utilize polybutylene terephthalate, polyglycolic acid (PGA) and ~~polytetramethylene oxalate (PO)~~ as homopolymers.

- 5 The transesterification reaction carried out under the conditions detailed in Example I yielded a copolymer containing PBT:PGA in the ratios of 90:10 and 95:5 (weight per cent).

EXAMPLE I

The reaction flask in which the copolymer was to be prepared was dried thoroughly and flushed with an inert gas. The following reaction mixture was then added to the flask and the flask heated to 235°C under
5 vacuum (2 - 4 mm. Hg) for 2 hours.

4.5 g polybutylene terephthalate

0.5 g polyglycolic acid

0.1 - 0.2 ml stannous octoate catalyst (0.33M solution
in dry toluene: 0.3 - 0.5 % by weight of PBT)

10 The reaction mixture attained a tan brown color and was allowed to cool to room temperature under an atmosphere of nitrogen. It was then crushed and purified by heating with ethyl acetate under reflux for 20 minutes. The intrinsic viscosity of the resulting copolymer was determined to be about 0.95 dl/g.

15 Preparation of the 95:5 copolymer was accomplished by taking PBT and PGA in the appropriate ratios and following the same procedure as described above for the 90:10 copolymer above. The intrinsic viscosity of this copolymer was found to be about 0.95 dl/g.

The preparation of polybutylene terephthalate-co-polytetramethylene oxalate was carried out in accordance with Example II. The resulting PBT-PTMO copolymer was prepared in the ratios of 90:10 and 70:30 (weight per cent).

EXAMPLE II

The reaction flask in which the copolymer was to be prepared was dried thoroughly and flushed with an inert gas. The following reaction mixture was then added to the flask and the flask heated to 235 - 240°C
5 under vacuum (2 - 4 mm Hg) for 2 hours.

45 g polybutylene terephthalate

5 g polytetramethylene oxalate

0.1 - 0.2 ml stannous octoate catalyst (0.33 M solution
in dry toluene)

10 The mixture attained a tan brown color and was allowed to cool to room temperature under an atmosphere of nitrogen. It was then crushed to a fine powder and the intrinsic viscosity of the copolymer was determined to be about 1.08 dl/g.

Preparation of the 70:30 copolymer was carried out by taking the
15 PBT and PTMO in the appropriate ratios and following the procedure as described for the 90:10 copolymer above. The intrinsic viscosity of this copolymer was found to be about 1.1 dl/g.

The copolymers produced by Examples I and II were characterized by NMR using a Bruker 200MHz instrument (80:20 V:V mixture of deuterated chloroform and deuterated trifluoroacetic acid as the solvent). Thermal analysis of the samples was carried out in a Perkin-Elmer 7

5 series Differential Scanning Calorimeter. Hydrolysis of the copolymers was followed by viscometry using a Cannon-Ubbelohde viscometer and a 3/5 (V/V) phenol and tetrachloroethane solvent maintained at 3°C, 33°C, and 50°C.

10 NMR studies of the PBT-PGA polymer indicated that the polymer obtained is a true copolymer and not a blend. The methylene absorption of the copolymer was seen at five individual peaks between 4.8 and 5.38 as would be expected from the random to blocky placement of the glycolide repeat units along the PBT backbone.

15 Thermal analysis of the copolymer of PBT-PGA showed a slight depression in the melting temperature for the higher molecular weight products. The low molecular weight copolymers showed a greater depression in the melting temperature. The heat of fusion (a measure of the % crystallinity) of the copolymer increased and then decreased over a period of 50 to 55 days for the samples maintained at 60°C.

20 The viscometric studies in Tables 1, 2 and 3 indicate a significant decrease in the intrinsic viscosity (indicative of a change in molecular weight of the copolymer and also of a change in the physical properties for the polymer) of copolymers made in accordance with the present invention when hydrolyzed in water.

TABLE 1
(PBT-PGA 95:5)

		Intrinsic Viscosity		
	<u>Days</u>	<u>3°C</u>	<u>33°C</u>	<u>50°C</u>
5	3		0.44	0.48
	4	0.41		
	12		0.42	0.40
	15	0.40		
	16		0.41	0.39
10	20	0.40		0.35
	24			0.34
	40			0.34
	50	0.36	0.36	
	55	0.39		
15	62		0.35	
	77		0.29	

TABLE 2
(PBT-PGA 90:10)

Intrinsic Viscosity

	<u>Days</u>	<u>3°C</u>	<u>33°C</u>	<u>50°C</u>
5	0			0.55
	4	0.39		0.38
	6		0.41	
	12	0.35		0.36
	16		0.40	0.33
10	20	0.35		0.30
	40			0.27
	50		0.27	
	55	0.38		
15	62	0.39	0.28	
	72	0.38		
	77		0.29	

TABLE 3

(PBT-PO)

Intrinsic Viscosity

20	<u>Days</u>	<u>99:1</u>	<u>90:10</u>	<u>70:30</u>
	0	0.99	1.09	1.21
	5	0.98	0.41	0.11
	10	0.86		0.09
25				

The intrinsic viscosities of the samples, as tabulated in Tables 1 and 2 for PBT-PGA copolymer and in Table 3 for PBT-PO copolymer, decreased at different rates depending upon the temperature at which

they were maintained. The decrease in intrinsic viscosity implies that the copolymeric material degrades to lower molecular weight with water. These data indicate that the viscosity falls at a faster rate at higher temperature and that the rate of degradation is increased as the weight percent of the PGA is increased.

Fiber formation utilizing both polyglycolic and polyoxalate as the random hydrolyzable groups in the polyester co-polymer backbone have been successfully carried out using a single screw laboratory scale extruder.

Although the polymeric ratio is a matter of choice depending upon the physical characteristics of the final copolymer desired, the copolymers of the present invention may also be manufactured as a concentrate having the aromatic polyester moiety as a minor proportion (by weight per cent), and the hydrodegradable link polymer as the major proportion. For example, the concentrate can easily be prepared and stored as a 5:95 polyester: hydrolyzable moiety copolymer. Prior to the manufacture of a product utilizing the random copolymers of the present invention, the concentrate would have the bulk of the polyester material added to it to arrive at the desired polymeric concentration. For example, by adding additional bulk PBT polyester to a 5:95 PBT:PGA concentrate, the final copolymer prepared from this material can be adjusted to have the 95:5 ratio of the copolymer in Table 1. Of course, present polymeric compositions are considered to be concentrates in accordance to the present invention, and the addition of a hydrolyzable moiety to these concentrates to achieve a hydrodegradable link polymer.

Thus, while we have illustrated and described the preferred embodiments of our invention, it is to be understood that this invention is capable of variation and modification, and we therefore do not wish to be limited to the precise terms set forth, but desire to avail ourselves of such
5 changes and alterations which may be made for adapting the invention to various usages and conditions. Accordingly, such changes and alterations are properly intended to be within the purview of the following claims.

Having thus described our invention and the manner and process of making and using it in such full, clear, concise and exact terms so as to
10 enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to make and use the same:

WE CLAIM:

1. A copolymer comprising an aliphatic or aromatic polyester and a random hydrodegradable link polymer within the backbone of the polymer.
2. A copolymer according to Claim 1 wherein the polyester is aromatic.
3. A copolymer according to Claim 1 wherein the hydrodegradable link polymer is a glycolide, lactide, oxalate, adipate, siloxane or anhydride moiety.
4. A copolymer according to Claim 1 wherein the amount of polyester in the copolymer is greater than the amount of the hydrodegradable link polymer.
5. A copolymer according to Claim 1 wherein the amount of polyester in the copolymer is less than the amount of the hydrodegradable link polymer.

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US90/04318

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶

According to International Patent Classification (IPC) or to both National Classification and IPC
 IPC (5): C08G 63/16, 63/18, 63/60, 64/06, 81/00
 U.S. CL. 525/411, 413, 419, 437, 440, 444; 528/176, 194, 196, 302

II. FIELDS SEARCHED

Minimum Documentation Searched ⁷	
Classification System	Classification Symbols
U.S.	525/411, 413; 528/176, 196, 302

Documentation Searched other than Minimum Documentation
 to the Extent that such Documents are Included in the Fields Searched ⁸

III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹

Category [*]	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	US, A, 3,784,585 (SCHMITT) 08 JANUARY 1974 See examples.	1-4
X	Polymer, Vol. 22, April 1981, A.M. Reed et al Biodegradable polymers for use in surgery-- pages 499-504. See experimental and results at pages 500-504.	1, 2, 4 & 5

^{*} Special categories of cited documents: ¹⁰

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- "&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search

08 NOVEMBER 1990

International Searching Authority

ISA/US

Date of Mailing of this International Search Report

20 DEC 1990

Signature of Authorized Officer

Patricia Short

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE¹

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers _____, because they relate to subject matter ^{1.2} not required to be searched by this Authority, namely:

2. ☐ Claim numbers _____, because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out ^{1.3}, specifically:

3. ☐ Claim numbers _____, because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☒ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING²

This International Searching Authority found multiple inventions in this international application as follows:

Copolymer with hydrodegradeable link polymer that is:

I. glycolide - claims 1-5
II. lactide - claims 1-5
III. oxalate - claims 1-5

IV. adipate - claims 1-5
V. siloxane - claims 1-5
VI. anhydride - claims 1-5

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

Glycolide - claims 1-5.

4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.

